Available online at www.sciencedirect.com
ScienceDirect
Energy Procedia 95 (2016) 324 – 329
Energy Procedia

International Scientific Conference "Environmental and Climate Technologies", CONECT 2015, 14-16 October 2015, Riga, Latvia

Thermal conductivity of heat insulation material made from coniferous needles with potato starch binder

Indra Muizniece*, Dagnija Blumberga

Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Riga, LV–1048, Latvia

Abstract

In previous experiments made by authors of this research about the possibilities to produce thermal insulation material from coniferous greenery (needles and thin branches), it was found that there is not enough natural resin in coniferous greenery to make sufficiently strong thermal insulation material plates. Therefore it is necessary to add some binder. Potato starch glue was selected as a natural and environmentally friendly binder. For that reason, the aim of the experiments in this study is to evaluate how the quantity of potato starch binder influences the thermal conductivity coefficient of the coniferous needle thermal insulation material. In this study two experiments were performed investigating two factors – proportion of the binder and the coniferous species (pine or spruce). In the first experiment milled fresh coniferous greenery with potato starch binder was used. In the second experiment potato starch was used to band dried needles without the branches. Granulometric content of the raw material was determined in both cases. A total of 14 different samples were prepared and tested in this study, the thermal conductivity coefficient was determined in laboratory conditions for all of the samples. The results are compared with thermal conductivity coefficients of other thermal insulation materials. The possibility to use coniferous greenery to produce thermal insulation material is evaluated.

Peer-review under responsibility of Riga Technical University, Institute of Energy Systems and Environment.

Keywords: needles; coniferous; heat insulation; potato starch

* Corresponding author: Tel.: +371 29473353;
E-mail address: indra.muizniece@rtu.lv

Peer-review under responsibility of Riga Technical University, Institute of Energy Systems and Environment.
doi:10.1016/j.egypro.2016.09.014

1. Introduction

The demand for environmentally friendly and healthy products is steadily increasing. This also applies to building materials, which can have great effect on human health. It is therefore not surprising that new, environmentally friendly construction materials including thermal insulation materials are still actively studied. Demand for thermal insulation materials is increasing due to the growing costs of energy resources. Obtaining natural and environmentally friendly thermal insulation materials is an especially topical issue nowadays, when thermal insulation materials have become an extensively used product. This study is focussed on an ecological thermal insulation material made from coniferous forestry residues.

Plate-like thermal insulation material from coniferous greenery prepared without any additional adhesives or binders has been studied and described previously by the authors of this article [1]. The authors arrived at the conclusion that the resin naturally occurring in coniferous forestry residues is not enough to provide the firmness and particle adhesion necessary for insulation plates from coniferous greenery. Therefore it is necessary to find a solution in the form of a natural, environmentally friendly adhesive.

The use of various herbal origin adhesives for binding thermal insulation materials has been studied by various authors. For example, Palumbo M. et al. used corn starch and sodium alginate to produce thermal insulation materials from rice husk, corn pith and barley straw [2]. In other studies a raw rice husk thermal insulation material has been produced using a lime based binder [3]. Plaster and epoxy has been used as a binding material for thermal insulation materials from sunflower stalk, textile waste and stubble fibres by Hanifi Binici [4]. A common plant-based construction material adhesive is concrete [5–8].

The adhesive material obtained from mixture of potato starch and water was selected for this study. Up until this moment the potato starch adhesive has not been studied sufficiently as only few papers can be found in scientific databases [9, 10]. To our knowledge potato starch has not been evaluated in the context of its potential as adhesive material for plant-based thermal insulation materials. Therefore, the aim of this research is to evaluate if and how the quantity of potato starch binder influences the thermal conductivity coefficient of coniferous needle thermal insulation material.

2. Materials and methods

A two-factor experiment plan was performed before manufacturing and testing the coniferous greenery thermal insulation material with potato stark adhesive, thus ensuring an efficient determination of the effect and values of the set factors and the acquisition of qualitative results. The thermal conductivity coefficient was selected as the main response factor. The proportion of the selected adhesive is one of the factors that have to be assessed in order to reach the aim of this study. The second factor is the species of coniferous tree (spruce or pine). The previous studies confirmed that freely poured spruce and pine needles have different thermal conductivity coefficients [11], however the impact of the species for ground needles has not yet been determined [1]. In order to determine the effect of separating needles from other woody parts in the greenery on the thermal conductivity coefficient, it is necessary to obtain raw material that would consist only of single species needles of coniferous trees. This is technically possible if coniferous greenery is dried and the needles are falling off the branches. However, if the dried needles are minced, a mass of fine particles are formed. These fine particles were proved to have lower capacity to retain heat [12]. Therefore it was decided to carry out 2 experiments with a board-type insulation material (made using potato starch adhesive) with 2 unchanged factors, but varying the preparation methods.

Potato starch adhesive prepared in ratio 1:10 (1 part dry potato starch, 10 parts water) was used to bind the needles in the form of a plate-type thermal insulation material. In the first experiment (see Table 1) raw, coarse grind coniferous greenery is used. Milling machine (PM120 Vibrotehnik) with a sieve mesh size of 10 mm was used to grind the greenery. The minimal value of the adhesive part by weight to coniferous greenery mass was 1/2, maximal 1/1 and medium 1/1.5. This proportion was chosen based on laboratory experiments with small size (~10x10 cm) samples. From the small samples it was recognized that these proportions are proper to keep the needles together. But it is not based on the mechanical strength of the material.

To describe the species of the coniferous trees, it was assumed that the minimal value was pine greenery and maximal – spruce greenery, average value of this factor is a mix of both pine and spruce greenery with the ratio 1/1.

Table 1. Experimental plan for the plate-type coniferous insulation material from ground coniferous greenery and potato starch adhesive.

Factor	Sample No.				
	KC1	KC2	KC3	KC4	KC9, KC10, KC11
Tree species (spruce or pine)	Pine	spruce	spruce	pine	spruce 1 / pine 1
Rate of binder (binder / needles)	1/2	1/2	1/1	1/1	1/1.5

During the second experiment, the potato starch adhesive was added to air-dry (dried at 105 °C) pine or spruce needles, without the woody parts of greenery. The material was dried in a drawer-type drying stove (BMT ECOCELL) at 105 °C temperature for about 12 h. Dried needles are very dry (moisture content approximately 50 %), therefore it was necessary to increase the potato starch proportion to ensure that the samples hold their form. In this case, the minimal potato starch adhesive ratio against needle mass was 1/1, maximal ratio was 3/1, the average tested value was 2/1 (see Table 2).

Table 2. Experimental plan for the board-type coniferous insulation material from dried needles and potato starch binder.

Factor	Sample No.				
	SSKC5	SSKC6	SSKC7	SSKC8	KC12, KC13, KC14
Tree species (spruce or pine)	spruce	pine	pine	spruce	spruce 1 / pine 1
Rate of binder (binder / needles)	1/1	1/1	3/1	3/1	2/1

Seven board-type insulation material samples were prepared for each experiment. Three of them were prepared in the same way, taking into account the factor centre point values. The potato starch binder was manually mixed with the greenery mass and moulded in a 300×300 mm large form. The board thickness is 40–50 mm. An example of these insulation material samples is displayed in Fig. 1.


(a)


(b)

Fig. 1. Coniferous greenery insulation material samples No. KC2 (a) and SSKC7 (b).

Since the samples are made in different ways, it is not possible to compare the effect of grinding on the thermal conductivity coefficient. However, it is possible to compare the granulometric (size) composition in order to determine how significant the difference between the fineness of the spruce and pine grind is. Therefore granulometric content is determined (according to standard method LVS CEN/TS 15149-2:2011) for four raw material types: coarse and fine grind spruce and pine greenery.

Thermal conductivity coefficient was determined for each sample using LaserComp device, model FOX600 (according to standard ISO 8301:2012). The amplitude of the device temperature varies from -15 °C (5 °F) to 80 °C (176 °F) and the accuracy is 0.01 °C. Reproducibility of this apparatus is approximately 0.5%. When measuring the coniferous heat insulation material heat conductivity, the minimal temperature is 0 °C and maximum temperature -10 °C. Measurements were carried out with 1 % precision. The measurement principle of FOX600 is based on the measurement of heat flow between the upper plate (low temperature) and the lower plate (high temperature).

Using the data processing program *Statgraphics,* regression analysis was performed to determine the correlation between the thermal conductivity coefficient and the selected experimental factors, i.e., tree species and the binder/needles ratio.

3. Results and discussion

The thermal conductivity coefficient results obtained from material samples for both types of coniferous board-type insulation materials are summarized in Table 3. The calculation of measurement error at a given confidence probability of 95 % (coefficient τ_{95} = 1.412) showed that all the measurement results are reliable. As you can see from the results, thermal conductivity coefficients are in the amplitude from 0.0478 W·(m·K)$^{-1}$ to 0.0551 W·(m·K)$^{-1}$. The sample made of air-dried spruce needles with potato starch in a weight ratio of 1/1 had the lowest (best) thermal coefficient. The worst thermal conductivity coefficient was observed for the sample made from ground raw (green) spruce and pine greenery with an adhesive in proportion 1/1.5.

The regression analysis was performed for the thermal conductivity coefficient of the samples from the first experiment that were produced from grounded coniferous greenery. The results showed that, in this case, the spiecies of the coniferous tree does not have any significant effect on the thermal conductivity coefficient. There is only a moderate correlation (correlation coefficient -0.325).

Table 3. Thermal conductivity coefficient λ values of coniferous insulation materials with potato starch adhesive, W·(m·K)$^{-1}$.

Sample number	Thermal conductivity coefficient, W·(m·K)$^{-1}$	Uncertainty, %	Sample number	Thermal conductivity coefficient, W·(m·K)$^{-1}$	Uncertainty, %
KC1	0.0549	±2	SSKC5	0.0478	±2
KC2	0.0495	±2	SSKC6	0.0508	±2
KC3	0.0513	±2	SSKC7	0.0543	±2
KC4	0.0496	±2	SSKC8	0.0497	±2
KC9	0.0551	±2	SSKC12	0.0513	±2
KC10	0.0544	±2	SSKC13	0.0497	±2
KC11	0.0525	±2	SSKC14	0.0524	±2

The proportion of the adhesive had even less impact on the thermal conductivity coefficient (correlation coefficient -0.296). However, strong correlation (correlation coefficient 0.740) was observed between the species of coniferous trees and the thermal conductivity coefficient during the second experiment, where needles were prepared in the form of a plate-like insulation material consisting only of unground, dried needles, without any woody parts. Thermal conductivity coefficient is lower for samples made out of dried spruce needles (λ = 0.0478 W·(m·K)$^{-1}$ and λ = 0.0497 W·(m·K)$^{-1}$). These samples also show moderately high correlation (correlation coefficient 0.524) between the proportion of the adhesive material and the thermal conductivity coefficient.

The amount of adhesive impacts the thermal conductivity coefficient in one of the experiments, but does not do so in the others. This is most likely because, in the case of the samples that were impacted by the amount of the adhesive, the difference between the minimal and maximum value of adhesive was bigger. Thus, we can conclude that a larger amount of potato starch adhesive also has a more negative influence on the material capacity to retain heat. Therefore, the minimal amount of the adhesive necessary to ensure the structural integrity of the material respective to its size must be used when producing thermal insulation materials. These experiments revealed that, in a ground form, the thermal conductivity of the greenery of different coniferous species does not have significant difference. The species of the coniferous trees must be taken into account if the needle insulation material is produced from whole coniferous needles.

Fine grind coniferous greenery was used as the raw material in the previous experiments [1]. Granulometric (size) composition was determined in order to assess how significant is the difference between the grind levels of spruce and pine greenery. The granulometric composition determination results are graphically displayed in Figure 2.

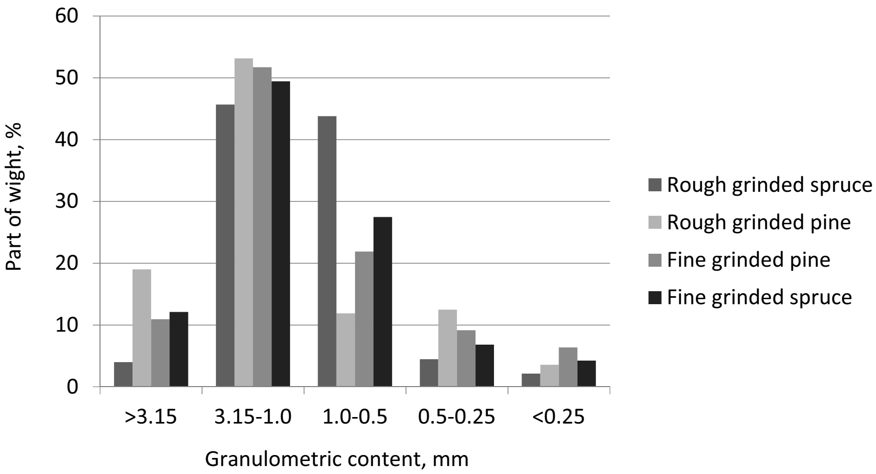

Fig. 2. Size composition of plate-type thermal insulation materials.

From the obtained results it can be seen that the amount of the fine fraction that is smaller than 0.25 mm is approximately the same for all the samples. Distribution of the fractions is very similar for both - finely ground pine and spruce. This means that for samples produced from finely ground pine or spruce greenery, the differences in granulometric (size) composition between the species could not have any impact on the results (thermal conductivity coefficient). It is different in the case of coarsely ground pine and spruce greenery when there is a difference between the distribution of coarse particle fractions. There are distinctly more pine particles with dimensions above 1 mm. This could be because a large proportion of the spruce needles is not crushed in the coarse grinding process. Spruce needles, that are smaller than 1 mm in diameter, are included in the fraction with particle size 1.0–0.5 mm. Unground pine needles remain on the sieve. A significant thermal coefficient difference between samples made of coarse pine or spruce greenery was not observed. This leads to a conclusion: granulometric (size) composition of coniferous greenery does not affect thermal conductivity of plate-type thermal insulation material. However, it may be important in relation to the amount of adhesive to be added. During the preparation of the samples, inferior adhesive properties were observed in the samples that were made from coarsely ground raw material or if there were more unground particles left in the material.

4. Conclusion

Based on the two-factor experimental plan, thermal conductivity coefficients, and their dependence from the species of coniferous trees, and the amount of adhesive added to the material are determined for plate-like thermal insulation material produced from coniferous greenery (needles with small branches) or dried needles, and potato starch adhesive.

Experiments proved that the more potato starch adhesive is added to the needle thermal insulation material, the more negative is its impact on the material's ability to detain heat. Therefore, a minimal amount of adhesive that can still ensure the necessary physical properties of the material should be used to produce this type of thermal insulation material.

This study proved that thermal conductivity of pine and spruce needles in ground form have no significant differences. Species of the coniferous trees must be taken into account if thermal insulation material is produced from non-deformed needles.

Granulometric (size) composition of coniferous greenery does not affect the thermal conductivity of a plate-type thermal insulation material. However, it may affect the amount of adhesive necessary, because a smaller binding capacity is observed for materials produced from coarser raw material or materials with more unground particles left inside.

The impact of the potato starch amount in the coniferous needle heat insulation material on the mechanical strength was not explored in this research. But it is a very important factor that describes the durability of the heat insulation material panel's parameters. It is necessary to do additional research on this matter.

Acknowledgements

The work has been supported by the National Research Program "Energy efficient and low-carbon solutions for a secure, sustainable and climate variability reducing energy supply (LATENERGI)".

References

[1] Muizniece I, Blumberga D, Ansone A. The use of coniferous greenery for heat insulation material production. Energy Procedia 2015;72:209–215.
[2] Palumbo M, Formosa J, Lacasta AM. Thermal degradation and fire behaviour of thermal insulation materials based on food crop by-products. Construction and Building Materials 2015;79:34–39.
[3] Chabannes M, Bénézet JC, Clerc L, Garcia-Diaz E. Use of raw rice husk as natural aggregate in a lightweight insulating concrete: An innovative application. Construction and Building Materials 2014;70:428–438.
[4] Binici H, Eken M, Dolaz M, Aksogan O, Kara M. An environmentally friendly thermal insulation material from sunflower stalk, textile waste and stubble fibres. Construction and Building Materials 2014;51:24–33.
[5] Johnson Alengaram U, Muhit BAA, Jumaat MZ, Jing MLY. A comparison of the thermal conductivity of oil palm shell foamed concrete with conventional materials. Materials & Design 2013;51:522–529.
[6] Jianga D, Cuia S, Song X, Zhang J. Analysis of micro-morphology and heat-insulating property of leaf concrete. Construction and Building Materials 2013;49:663–671.
[7] Madurwar MV, Ralegaonkar RV, Sachin A. Mandavgane. Application of agro-waste for sustainable construction materials: A review. Construction and Building Materials 2013;38:872–878.
[8] Tran Le AD, Maalouf C, Mai TH, Wurtz E, Collet F. Transient hygrothermal behaviour of a hemp concrete building envelope. Energy and Buildings 2010;42(10):1797–1806.
[9] Yu W, He H, Cheng N, Gan B, Li X. Preparation and experiments for a novel kind of foundry core binder made from modified potato starch. Materials & Design 2009;30(1):210–213.
[10] Cheyne A, Barnes J, Gedney S, Wilson D.I. Extrusion behaviour of cohesive potato starch pastes: II. Microstructure–process interactions. Journal of Food Engineering 2005;66(1):13–24.
[11] Muizniece I, Lauka D, Blumberga D. Thermal Conductivity of Freely Patterned Pine and Spruce Needles. Energy Procedia 2015;72:256–62.
[12] Muizniece I, Blumberga D. Granulometric composition influence on coniferous needle thermal conductivity. International Scientific Conference on Environmental and Climate Technologies, Riga, Latvia, 14–17 October 2014:71–2.